ATOLL RESEARCH BULLETIN

NO. 555

THE IMPACTS OF CORAL BLEACHING IN RODRIGUES, WESTERN INDIAN OCEAN

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ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C. U.S.A.
DECEMBER 2007

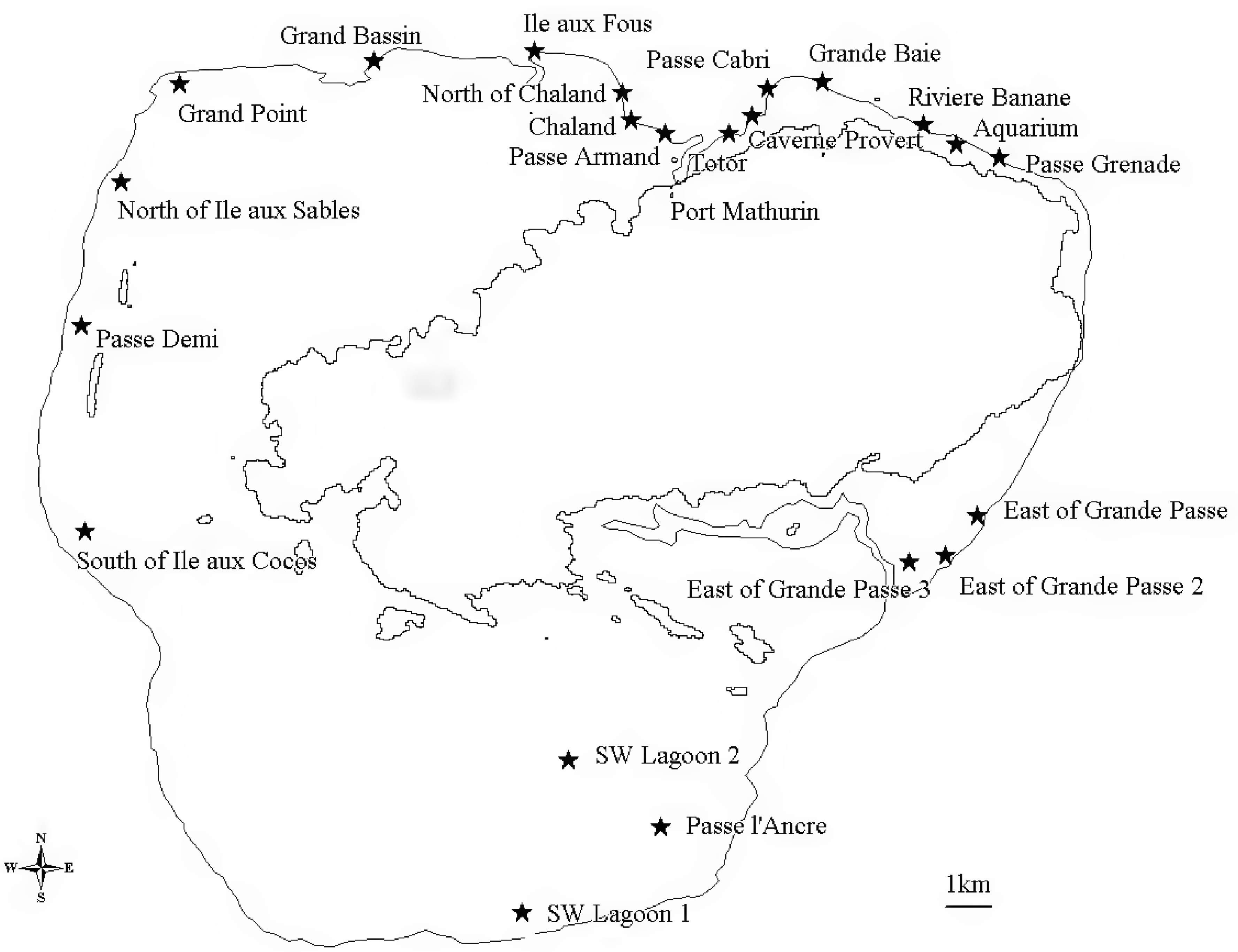

Figure 1. Location map of Rodrigues showing the location of the 22 survey sites.

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ABSTRACT

Rapid assessments of the degree of coral bleaching were carried out at 22 sites around the coast of Rodrigues during March-April 2005 and April-May 2006. During 2005, coral bleaching was observed at all sites, but the worst affected sites were in the north and west of the island. Bleaching was most severe on the shallow reef flats at depths of 0.5–2m, but also occurred on the reef slopes down to depths of 5–6m. It is suggested that the bleaching occurred due to a combination of high sea temperatures, high solar illumination and exposure. The worst affected species were *Acropora* spp. and *Porites rus*; partial bleaching also affected massive coral colonies, soft corals, zoanthids and anemones. No coral bleaching was observed during the 2006 surveys and all sites had recovered from the bleaching except for Totor in the north. At this site, dead standing coral cover was 15% and the site was dominated by turf algae. This site suffered from severe bleaching in 2002 and is also subjected to impacts from sedimentation and trampling, which may account for the mortality. There was a low abundance of coral recruits but a high abundance of the sea urchin, *Echinometra mathaei*, at this site, suggesting that recovery is limited and that erosion of the reef structure may occur. Rodrigues was also affected by coral bleaching during 2002 and bleaching occurred at other Western Indian Ocean sites in 2002, 2003 and 2004. Rodrigues is a small, isolated island and if coral bleaching events continue to occur on such a frequent basis then this will affect the integrity of the reef structure, leaving the island vulnerable to coastal erosion and storm damage.

INTRODUCTION

The coral reefs of Mauritius and Rodrigues were some of the few reef areas in the Indian Ocean to escape the mass coral bleaching event of 1997-1998 (Turner et al., 2000). However, unusually warm and calm conditions occurred during February 2002 resulting in coral bleaching, particularly at sites in the north and west of Rodrigues. Surveys showed that although the bleaching was not widespread, it was severe where

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Manuscript received 19 April 2007; revised 25 June 2007.

it did occur, resulting in mortality of up to 75% of corals at some sites. Coral species most vulnerable were *Acropora cytherea* and *Acropora abrotanoides,* which suffered up to 100% mortality (Hardman et al., 2004). Minor coral bleaching was also observed in 2003; however, this did not result in significant mortality of coral colonies (Lynch et al., 2004).

During February and March 2005, anomalously high sea surface temperatures (SST) developed in the Western Indian Ocean and National Oceanic and Atmospheric Administration (NOAA) SST charts suggested that the accumulation of thermal stress was conducive to bleaching with HotSpot values >0.5 for the two-month period (NOAA/NESDIS/OSDPD, 2005). Anecdotal evidence of coral bleaching in northeast Madagascar, Mauritius and Réunion was reported during March and April. Significant bleaching at a depth of 2-4 m was reported in Madagascar with 80% of massive corals and 50% of encrusting corals displaying either total or partial bleaching (S. Harding, pers. comm.); soft corals, anemones and giant clams also were affected. Mild and patchy bleaching was reported in Réunion (J. P. Quod, pers. comm.) and 25-30% bleaching was observed in Mauritius (O. Tyack, pers. comm.), with *Acropora hyacinthus* and *A. muricata* most severely affected. Rodrigues experienced temperatures 1.5°C above average, high solar radiation and low wind during February and March and SSTs reached up to 32°C in the shallow lagoon (Mauritius Meteorological Services unpublished data). Coral bleaching was observed on the shallow reef flat at Passe Cabri, where the majority of *Acropora austera*, *A. abrotanoides* and *A. digitifera* colonies were bleached at 1–2 m depth; *A. cytherea* and *A. formosa* colonies also displayed partial bleaching.

The aim of the study was to assess the extent and severity of coral bleaching and mortality around Rodrigues and to investigate the impact of this bleaching on reef health.

METHODS

In order to make an estimate of the extent of coral bleaching and coral mortality around the whole of Rodrigues, rapid assessment surveys were carried out at 22 sites around the island during March and April 2005 and April and May 2006 (Turner et al., 1999) (Fig. 1). Sites were identified on the reef flat, reef slope and on the patch reefs within the lagoon. The location of the site was obtained using a hand-held Global Positioning System (GPS) (Magellan GPS 315, datum set to WGS-84) and weather conditions, exposure and tidal height were recorded.

Surveys were carried out using snorkeling techniques by a team of 3-4 personnel. Surveys on the reef flat were carried out at high tide so that surveyors could swim into the lagoon over the reef front and thus assess bleaching on the reef slope down to a depth of 5–6m. Surveyors swam across the reef area for two minutes and then stopped and recorded the occurrence of bleaching within an area of approximately 5m x 5m. This was repeated to give a total of 20 observations per site. During each observation for each coral genus observed, the abundance of the genus and the percentage of colonies of that genus that was recently dead (still standing, but covered in a thin layer

of turf algae), bleached (pale to completely bleached) and healthy was recorded on a 6-point semi-quantitative scale (0 = 0%; 1 = 1-10%, 2 = 11-30%, 3 = 31-50%, 4 = 51-75% and 5 = 76-100%) (Turner et al., 1999). The bleaching values for each genus were then averaged and multiplied by the abundance score for that genus to give a bleaching score for each coral genus observed. These values were then averaged to produce a mean bleaching value for each site.

During May–June 2006, additional detailed surveys were undertaken at three sites: Totor, Passe Cabri and East Grand Passe. Three 50m transect lines were laid on the reef flat parallel to the reef edge and separated by a distance of 10m. The abundance of five fish families (Acanthuridae, Chaetodontidae, Balistidae, Pomacentridae and Scaridae) was determined by swimming along these transects and recording fish 2m either side of the line. Benthic community was assessed along the first 20m of each of the transects using the line intercept transect method (English et al., 1994) and sea-urchin abundance was determined by counting all of the individuals within thirty $1m^2$ quadrats randomly placed along the transects. The abundance of coral recruits (colonies <10cm in diameter) was also assessed by counting all of the colonies within thirty $0.25m^2$ quadrats laid within the $1m^2$ sea-urchin quadrats.

RESULTS

During 2005, coral bleaching was observed at all 22 sites surveyed around the coast of Rodrigues; however, the most severely affected sites were situated in the north and west of the island. Analysis of Similarities (ANOSIM) shows that this difference was significant with corals in the north and west showing significantly higher bleaching values than those in the south and east (Global $R = 0.314$, $p = 0.002$). Coral bleaching was most severe on the shallow reef flats at depths of 0.5–2m, but also occurred on the fore-reef slopes down to depths of 5–6m. The worst affected sites were Totor, Passe Armand and Chaland in the north, which had a mean bleaching score of three, indicating that 31–50% of all corals were bleached. Sites at Passe Cabri, Caverne Provert, Grand Bassin, North Chaland and Ile aux Fous in the north and at South Ile aux Cocos and Passe Demi in the west had a mean bleaching score of two. The remaining sites showed low, patchy bleaching (mean score of one) and very little bleaching was observed at Grand Point in the northwest and Southwest Lagoon 1 (mean score <1). Coral mortality was observed at Grand Bassin, Ile aux Fous, Chaland and Passe Armand (Fig. 2).

Cluster analysis separates the sites into four distinct groups, with sites in the north, which had a high severity of bleaching of branching, tabular, digitate and encrusting *Acropora* spp., grouping together at 74% similarity (Figs. 3 and 4). Sites with high bleaching of branching and tabular *Acropora* spp. group together at 66% similarity; sites in the north and east with moderate bleaching of branching and encrusting *Acropora* spp, and branching and encrusting corals (*Porites rus and Montipora*) group together at 76% similarity; and sites in the south and west with low bleaching of branching *Acropora* spp. group together at 61% similarity. The two sites with the lowest occurrence of bleaching, Grand Point and Southwest Lagoon 1, appear distinct from the other 20 sites.

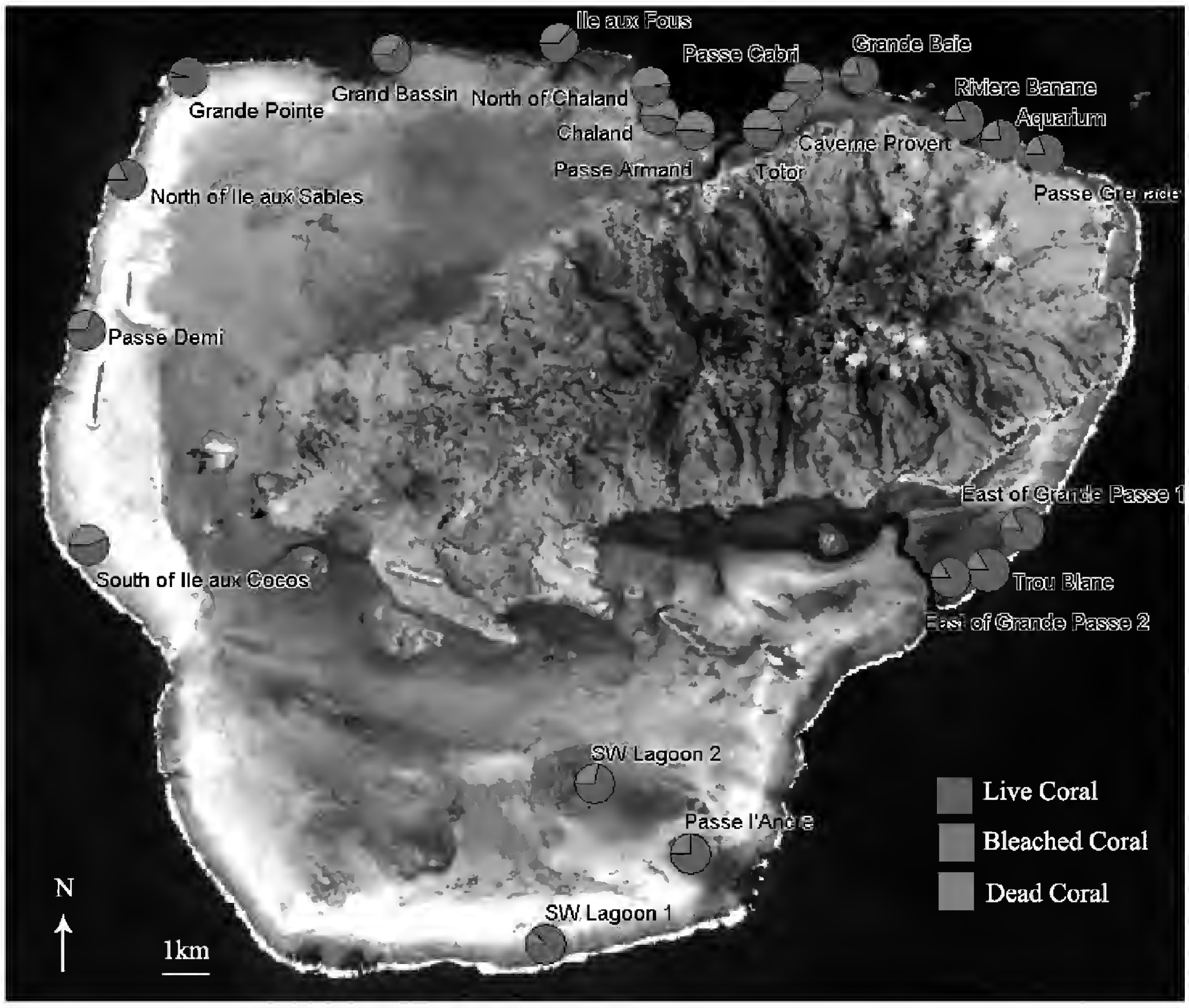

Fig. 2. The percentage of live, bleached and dead coral at the 22 survey sites around the coast of Rodrigues in March-April 2005.

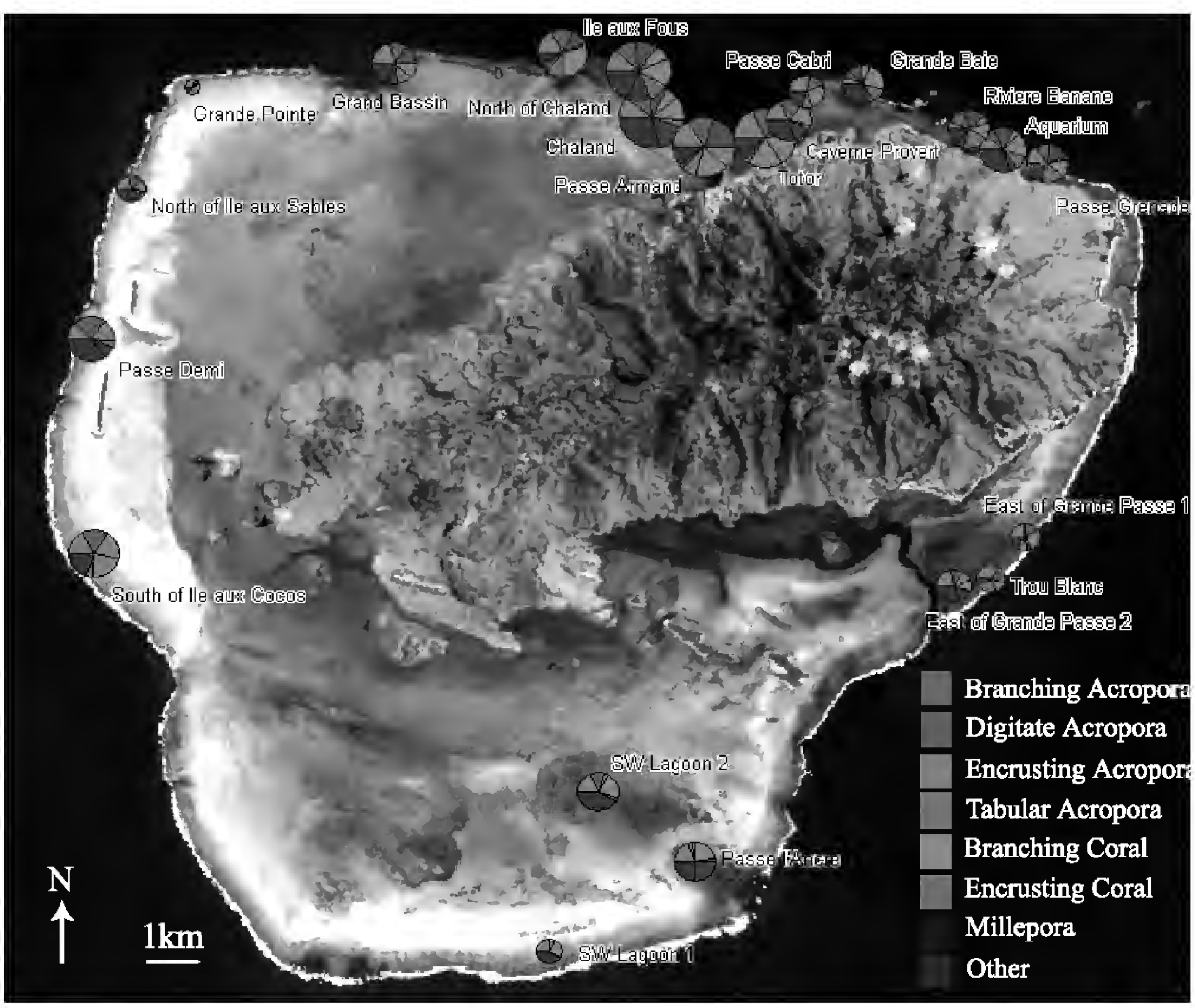

Fig. 3. The percentage of coral growth forms affected by bleaching at the 22 survey sites around the coast of Rodrigues in March-April 2005.

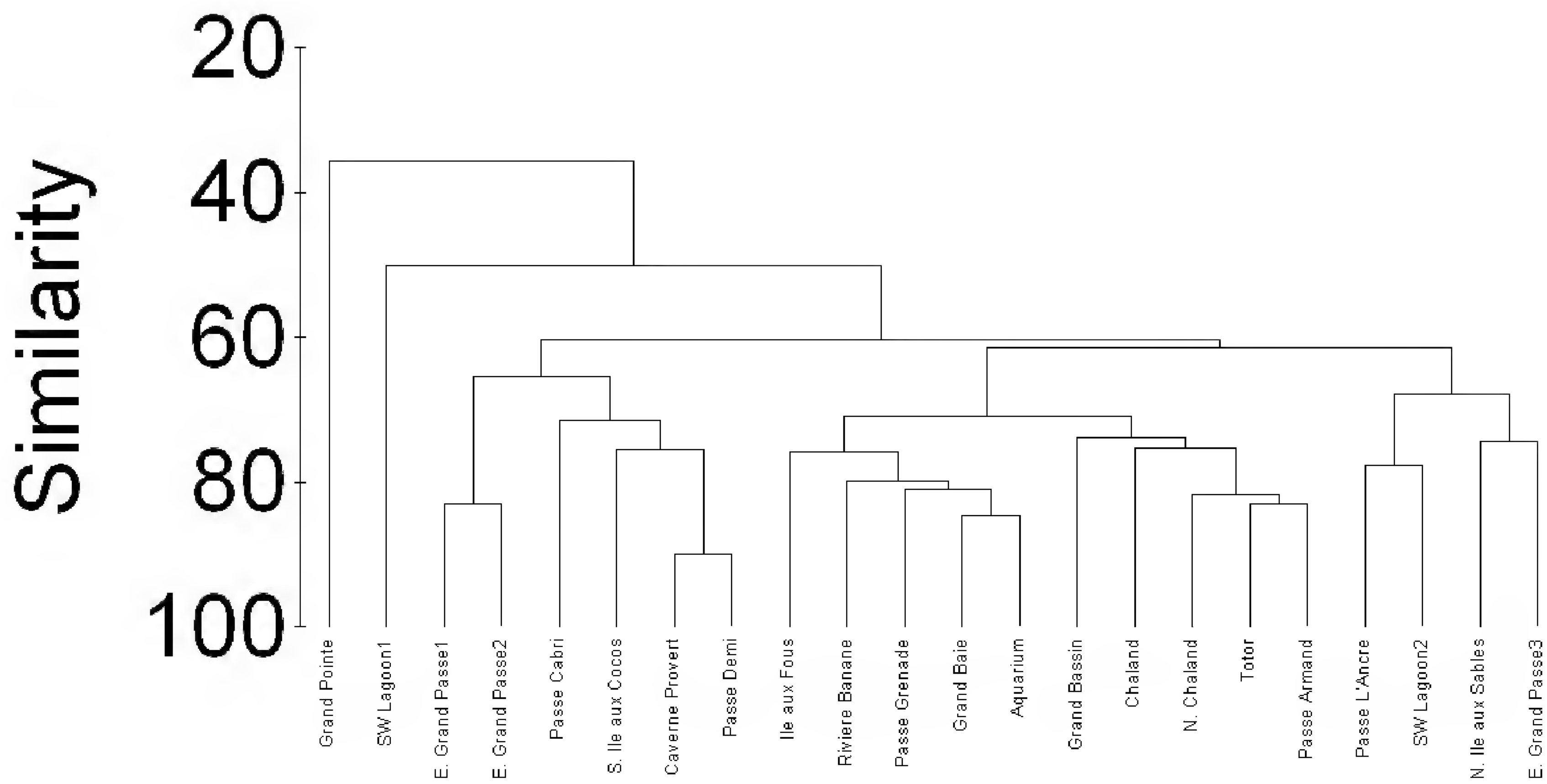

Fig. 4. Cluster analysis (√-transformed) of the degree of coral bleaching at the 22 survey sites during March-April 2005.

Fifty-one of the 80 benthic species observed exhibited either partial or total bleaching. The most severely affected species were branching, digitate, encrusting and tabular *Acropora* spp. and *Porites rus* (Table 1), which had mean bleaching scores of between two and four and were bleached at over 35% of sites surveyed. Sub-massive corals such as *Pocillopora* and *Stylophora* were bleached at sites in the south and west and partial bleaching affected massive coral colonies (*Platygyra* and *Symphyllia*) as well as *Galaxea, Hydnophora* and *Favia*. In addition to hard coral colonies, soft corals (*Sinularia*, *Sarcophyton*, *Xenia), Millepora,* the zoanthid *Palythoa* and the anemone *Heteractis* were also bleached.

Table 1. The mean percentage bleaching (based on a semi-quantitative scale) and the percentage of sites at which that species was bleached for the 15 most severely affected species recorded at the 22 reef sites around Rodrigues.

Genus	**Mean % Bleaching (Score)**	**Mean % Sites**
Pocillopora	1 – 10 (1)	59
Stylophora	11 – 30 (2)	36
Montipora	31 – 50 (3)	32
Acropora (branching)	51 – 75 (4)	100
Acropora (tabular)	11 – 30 (2)	59
Acropora (digitate)	11 – 30 (2)	59
Acropora (encrusting)	51 - 75 (4)	50
Porites rus	51 – 75 (4)	36
Galaxea	31 – 50 (3)	23
Symphyllia	76 – 100 (5)	9
Hydnophora	11 – 30 (2)	36
Favia	1 – 10 (1)	36
Platygyra	1 – 10 (1)	36
Millepora	31 – 50 (3)	27
Heteractis	11 – 30 (2)	14

At 91% of the sites surveyed during 2006, 76-100% of coral colonies were healthy and showed no sign of bleaching or recent mortality. Minor bleaching was observed at one site, Passe L'Ancre in the south, but this only affected <10% of coral colonies (branching *Acropora*); at Totor, however, 1–10% of coral colonies had recently died. Coral mortality was patchy affecting branching and tabular *Acropora* spp. in shallow water (<2m depth).

Detailed surveys of three of the sites indicate that live coral cover was low at all sites (<25%) and that sites were dominated by turf algae, with coralline algae also high (26%) at Passe Cabri (Table 2). The abundance of dead standing coral was 15% at Totor, but was <1% at the remaining two sites. The fish community at Totor and East Grand Passe was dominated by Pomacentridae, and Scaridae were also common at Totor (mean of 103 individuals per 250 m^2); the fish community at Passe Cabri was dominated by Acanthuridae. Chaetodontidae were not observed at East Grand Passe and no Balistidae were observed during the surveys. The abundance of *Echinometra mathaei* was high at Totor (20 individuals m^{-1}), but low at the remaining two sites. The number of coral recruits was lowest at Totor (1.72 recruits m^{-2}) and highest at Passe Cabri (3.20 recruits m^{-2}).

Table 2. The % cover ± SE, abundance of 5 fish families (Ind. 250m^{-2} ± SE), abundance of *Echinometra mathaei* (Ind. m^{-2} ± SE) and abundance of coral recruits (Ind. 0.25m^{-2} ± SE) at 3 sites in Rodrigues during May – June 2006.

		Totor	**Passe Cabri**	**East Grande Passe**
% cover	Living Hard Coral	20.6 ± 0.6	23.2 ± 4.9	21.0 ± 2.6
	Dead Coral	14.5 ± 10.6	0.5 ± 0.9	1.0 ± 0.5
	Soft Coral	0.82 ± 1.4	0.0	3.3 ± 2.0
	Turf Algae	34.2 ± 7.3	47.6 ± 5.8	36.4 ± 0.7
	Macro-Algae	1.6 ± 2.0	0.0	2.4 ± 4.5
	Coralline Algae	13.4 ± 3.3	26.1 ± 4.0	4.5 ± 2.2
	Sand	9.3 ± 9.8	2.6 ± 2.4	13.7 ± 0.5
	Rubble	6.5 ± 4.7	0.0	14.4 ± 6.1
Ind. 250m^{-2}	Acanthuridae	10.7 ± 7.8	173.0 ± 111.0	2.0 ± 1.7
	Balistidae	0.0	0.0	0.0
	Chaetodontidae	13.0 ± 7.8	16.3 ± 4.6	0.0
	Pomacentridae	118.3 ± 173.0	27.7 ± 11.6	550.0 ± 50.0
	Scaridae	103.0 ± 16.5	64.7 ± 54.0	2.0 ± 3.5
Ind. m^{-2}	*Echinometra mathaei*	20.1 ± 7.8	3.1 ± 4.4	2.3 ± 2.0
Ind. 0.25m^{-2}	Coral recruits	0.4 ± 0.6	0.8 ± 0.9	0.6 ± 1.1

DISCUSSION

The results show that the bleaching event in 2005 was more widespread than the bleaching event of 2002, with total or partial bleaching observed at all 22 sites and affecting more species (Hardman et al., 2004). As in 2002, coral bleaching was most severe in the north and west of the island, particularly at sites within the relatively sheltered Port Mathurin Bay area. Recent research has shown that water flow reduces the impacts of high sea surface temperatures, whereas in areas of decreased water flow, oxygen accumulates within the coral tissues, resulting in oxidative stress and an increased

severity of bleaching (Finelli et al., 2006). At the worst affected sites >75% of branching *Acropora* spp., the dominant species at these sites, suffered total bleaching, with other species including massive corals displaying partial bleaching.

Coral bleaching also occurred at other sites in the Western Indian Ocean at this time, such as Madagascar (S. Harding, pers. comm.), Mauritius (O. Tyack, pers. comm.) and Réunion (J.P. Quod, pers. comm.) and coincided with an accumulation of thermal stress in the region (NOAA/NESDIS/OSDPD, 2005). In Rodrigues, there were high air temperatures, high levels of solar radiation and low wind during February and March 2005 (Mauritius Meteorological Services, unpublished data), promoting heating of shallow water and increased solar penetration. Climatic conditions such as these have been shown to coincide with coral bleaching in past bleaching events (e.g., Brown and Suharsono, 1990) and were also observed preceding the 2002 bleaching event (Hardman et al., 2004). Coral mortality occurred on the shallow reef flats, mostly at depths of less than 2m. These corals are exposed at low tide suggesting a combination of high sea temperatures, high solar illumination and exposure as the causal factors.

Coral species most affected by the mortality were the branching and tabular Acroporids. Previous studies have shown that the fast growing Acroporids are most susceptible to coral bleaching and subsequent mortality (e.g., Brown and Suharsono, 1990; Gleason, 1993; Edwards et al., 2001). The loss of fast growing branching and tabular species may result in a change in species composition of the reefs with the faster growing species being replaced by the less susceptible slower growing species (Brown and Suharsono, 1990; McClanahan, 2000; Edwards et al., 2001). Slower-growing massive corals such as *Platygyra* and *Favia* also displayed partial bleaching; however, this tended to occur on the upper colony surfaces only and these corals recovered. In the southwest lagoon, partial bleaching of branching *Acropora* spp. also tended to occur on the upper branch surfaces only, suggesting high solar irradiation as the causal factor. Other studies have suggested that minor bleaching events are a seasonal phenomena occurring at times of the year when seawater temperatures and light levels are maximal (Oliver, 1985; Fagoonee et al., 1999). Indeed, partial bleaching of these species was also observed in the southwest lagoon in 2002 (Hardman et al., 2004) and at Passe L'Ancre during 2006.

Bleaching-induced mortality was low, affecting only corals at Totor; at all other sites corals appeared to have recovered from the 2005 bleaching event and were healthy. At Totor, dead standing coral was 15% on the reef flat (<2m depth) and the dead corals had been colonised by turf algae. Totor is a very sheltered site, situated only 500m from the shore at the entrance to the main shipping channel. Totor also experienced severe bleaching in 2002 and is subjected to high levels of sedimentation, especially following periods of heavy rainfall (Hardman, 2004) and also to trampling damage from octopus fishers (Clark, 2001). It is therefore likely that these additional stresses may have resulted in the mortality observed at this site. Lambo and Ormond (2006) also suggest that in Kenya, coral bleaching, sedimentation and fishing pressure have combined to result in further declines in live coral cover following the 1997/1998 coral bleaching event.

Dead coral colonies at Totor have now become colonised by turf algae and there is a low abundance of coral recruits suggesting that recovery of this site may

be limited. Previous studies have also found low larval settlement at this site, with settled recruits smothered by high levels of sediment (Hardman, 2004). Furthermore, as Rodrigues is influenced by the South Equatorial Current, which flows in a westerly direction, it receives a very limited larval supply suggesting that the reefs rely on larval retention and self-seeding for population recovery, leaving them more vulnerable to impacts. Graham et al. (2006) also conclude that, due to limited larval supply, isolated reefs may be the most susceptible to climate change-driven reef degradation, despite escaping many of the stressors impacting continental reef systems.

Totor also had a high abundance of the bio-eroding urchin, *Echinometra mathaei*. Bioerosion rates for *E. mathaei* have been estimated at 0.1– 0.2 g $CaCO_3$ ind^{-1} d^{-1} (Bak, 1990), which gives a maximum erosion rate at Totor of 1.5 kg $CaCO_3$ m^{-2} yr^{-1}. Values of gross carbonate production are generally 1–4 kg m^{-2} yr^{-1} (Bak, 1994); thus the bioerosion activity of *E. mathaei* may counteract up to 37.5–150% of the total calcification at Totor. This high level of bioerosion may result in loss of the coastal protection function of the reef, resulting in increased soil erosion, coastal flooding and loss of coastal property and habitats.

Although Rodrigues escaped the mass bleaching event of 1997/1998, coral bleaching events have occurred in 2002 and 2005 causing locally severe mortality, particularly in 2002, and bleaching has also occurred in Mauritius, Réunion, Madagascar and the Seychelles during 2002, 2003 and 2004 (Ahamada et al., 2004). It has been predicted that coral bleaching events will occur annually by 2030-2050 (Hoegh-Guldberg, 1999) and Sheppard (2003) estimates that reefs in the Indian Ocean will be affected every five years by 2010-2025. If coral bleaching events continue to occur on such a frequent basis, then this will affect the integrity of the reef structure causing breaks in the reef's protective barrier, leaving these areas vulnerable to wave action. Rodrigues is a very isolated island exposed to high winds, particularly during the cyclone season, and large oceanic swells and the loss of the protective barrier would result in increased coastal flooding and storm damage with loss of coastal habitats and significant damage to coastal properties.

ACKNOWLEDGEMENTS

This work was funded by the North of England Zoological Society and the New England Biolabs Foundation with additional funding for N. Stampfli provided by the Swiss Federal Institute of Technology Zurich. *Shoals Rodrigues* would also like to acknowledge the co-operation of the Rodrigues Regional Assembly, the Ministry for Agro-Industry and Fisheries and the Mauritius Oceanography Institute in the undertaking of this work.

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